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NAVY EXPERIMENTAL DIVING UNIT
WASHINGTON NAVY YARD
WASHINGTON, D. C. 20374

NAVXDIVINGU REPORT 19-74

TESTING PROCEDURES FOR
CLOSED-CIRCUIT AND SEMI-CLOSED CIRCUIT
UNDERWATER BREATHING APPARATUS

S. D. REIMERS

29 January 1974

Approved for public release; distribution unlimited.

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LCDR, USN
Officer in Charge
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LIST OF SYMBOLS AND TERMS

acfm	cubic feet per minute at ambient conditions
scfm	cubic feet per minute at standard conditions of 14.7 psia and 70°F, 1 scfm=26.29 slpm
ata	atmospheres absolute
psia	lbs per sq. in. absolute
psig	lbs per sq. in. gauge
psid	lbs per sq. in. differential
psiob	lbs per sq. in. over bottom pressure
RMV	respiratory minute volume
lpm	liters per minute at ambient conditions
alpm	liters per minute at ambient conditions, same as lpm
slpm	liters per minute at standard conditions of 14.7 psia and 0°C, 26.29 slpm = 1 scfm
cc	cubic centimeter
scc	cubic centimeters at standard conditions of 14.7 psia and 0°C
cm H_2O	centimeters of water pressure
Δp	differential pressure
free volume	free air space within a boundary
upper volume	the volume of a breathing bag/diaphragm system above which small increases in volume recuire large increases in Δp relative to outside ambient pressure
lower volume limit	the volume of a breathing bag/diaphragm system below which small decreases in volume require large negative increases in Δp relative to outside ambient pressure
ΔV	change in volume
UBA	underwater breathing apparatus

I. INTRODUCTION

The purpose of this protocol is to outline the general procedures and equipment to be used by EDU personnel in the evaluation of semi-closed circuit and closed circuit underwater breathing apparatus.

This protocol has been written in terms as general as possible consistent with clear understanding. It is not intended to be a step-by-step procedure which can be applied directly to the testing of a given peice of diving apparatus. Such a procedure would very quickly become out of date. It is rather intended as a detailed guide with which the Project Engineer can plan the evaluation of the apparatus to be tested. The quantities to be measures and controlled are specified for each type of test. The basic test equipment required is outlined along with the considerations governing its set-up, calibration and use. Typical test conditions and data handling requirements are also outlined for each type of test. With only a basic understanding of modern instrumentation and testing techniques, a Project Engineer should be able to readily make the detailed decisions necessary to apply this protocol to a specific piece of diving equipment.

The procedures outlined herein are concerned principally with evaluation of the <u>functional performance</u> of the diving apparatus being tested. No effort has been made to include specific material tests such as abrasion tests, salt spray tests, air-drop tests, etc. Those tests are very involved, very specific, and vary greatly with the system to be tested. They also, for the most part, require equipment and facilities not available at NAVXDIVINGU. Consequently they are considered outside the scope of this protocol.

If material adequacy tests are to be performed, U.S. Army Material Test Procedure 8-2-113 for Self-Contained Air and Oxygen Breathing Apparatus (1) contains most of the material tests that would be required. MTP 8-2-113 is, however, written for <u>surface</u> breathing apparatus (gas masks, dust masks, fire fighters breathing apparatus, etc.) and does not contain the material tests specific to underwater operation. The principal tests missing are those pertinent to MIL-STD-MS 33586 for dissimilar metals and MIL-STD-167 for a salt water spray.

Also, no effort has been made to include specific reliability and maintainability tests. These tests are normally done during the traditional Techeval/Opeval cycles. Considerable insight into the reliability and maintainability of the apparatus tested will, however, be gained as a result of the tests described herein.

The tests outlined herein have been kept as simple as possible. Experience has shown that it is usually faster and more reliable to run a number of small tests where no more than two or three major variables are measured at one time than it is to do everything all at once.

II. DESCRIPTION OF THE EQUIPMENT TESTED

A. Serial Numbers

It is critally important that the piece of diving apparatus be positively identified. Most underwater breathing apparatus have serial numbers. Find the serial number (a call to the manufacturer may be necessary to find where to look), and record it. All data sheets used with the UBA will need the UBA serial number. If the UBA does not have a serial number, give it one.

B. Photographs

1. Equipment Tested

Photograph the apparatus to be tested from all appropriate angles. Usually these will include at least both sides, front, and rear. Also, take several photos of a diver dressed in the apparatus. If appropriate, disassemble the apparatus and take pictures of the individual components.

Take all photographs against a white background. Place a dark-bordered white placard so that it appears in the lower right-hand corner of the picture, giving the following information: manufacturer trade name; view (front, back, right side, left side, op or bottom, etc.); month and year. For any close-ups of the apparatus, place a 12-inch ruler so that it appears across the bottom center of the picture. For long shots of the apparatus, do not include a ruler.

2. The Test Equipment

Photographs of the UBA as it is rigged for the various tests described herein are very helpful when report writing time arrives. Representative pictures should be taken of all test set-ups described, both with and without the UBA in place.

C. Physical Description

1. Material Description

A written description of the apparatus tested is essential. It must include a description of the overall apparatus configuration, the materials of construction, valve types and sizes, method of attachment to the diver (jocking system), communications arrangements, and any special features. Also to be detailed are the size, shape and absorbant capacity (in pounds) of the CO_2 absorbant canister, and the capacities (in scf), working pressures, shapes and methods of attachment of all gas storage bottles. Usually the manufacturer's own literature will be sufficient. However, if it is not, a description must be generated which meets the above requirements.

If possible, obtain exploded drawings of the apparatus from the manufacturer.

2. Size

Measure the overall size in inches. Include any projections. Record overall length, width and thickness, specifying the points of measurement. Record the size and shape of all display assemblies.

3. Weight

Measure the overall weight of the apparatus in air. Include all attachments. Record the apparatus weight with all bottles first empty, then charged to their maximum working pressure.

Record the individual weights of all display units.

4. Buoyancy

Measure the buoyancy in pounds and ounces, either positive or negative. Before checking the cylinder pressures, be sure that they have reached room temperature. Then record the buoyancy in room temperature fresh water under the following conditions:

a. Cylinder filled, canister filled with fresh dry Baralyme, breathing bags or diaphragm fully inflated.

b. Cylinder filled, canister filled with fresh, dry Baralyme, breathing bags or diaphragm as empty of air as it is possible to get them without damage.

Also measure separately the buoyancy, positive or negative, of all display units such as wrist or chest displays.

III. PERFORMANCE TESTS

A. Bench Tests

1. Pressure test all cylinders to their maximum rated pressure.

2. Disassemble entire rig (regulators, valves, canisters, mouthpiece, etc.), and check for any burrs, foreign matter imbedded, cracks and rough surfaces. Note any of these and any dissimilar metals as per MIL-STD-MS 33586. Note any difficulties encountered in either disassembly or re-assembly. Note any special or unusual tools required.

3. Test all relief and low pressure valves to their designated pressure.

4. After 1, 2, and 3 have been completed, submerge entire rig, fully charged, and check for leaks.

5. Test the testing equipment furnished by contractors.

6. Have subject put on fully charged rig and walk about. Determine from subject: comfort, pressure points, ease and ability to move about, and to walk erect.

B. Pressure Volume (Compliance) Characteristics

1. Background

All types of closed circuit and semi-closed circuit underwater breathing apparatus have a gas storage device or "counter-lung" somewhere in their design. The purpose of the "counter-lung" is to receive the diver's exhaled gas and store it at the ambient pressure so that it may be re-inhaled again at the proper time. The "counter-lung" designs most commonly used are breathing bags. Displacement diaphragms (a very low differential pressure version of a hydraulic accumulator) are also used.

For the purposes of this test protocol, the quantity "base pressure" will be defined to mean the pressure that exists in the respiratory circuit when there is no respiratory flow in the system. The base pressure in a breathing bag system is roughly equal to the external hydrostatic pressure at the level of the collapse plane of the breathing bags. In a diaphragm system, it is roughly equal to the hydrostatic pressure at the centerline level of the diaphragm.

In almost all systems, the base pressure will change with the inflation level of the breathing bags or the fill level of the diaphragm. This pressure change represents a form of resistance to breathing known as an elastic resistance. If severe enough, it can cause the apparatus to fail the breathing resistance standards, (see EDU report 19-73).

The purpose of this section is to determine the pressure-volume characteristics of the apparatus under test. The volume change per unit pressure change for the UBA is known as its respiratory "compliance". It is desirable that the compliance be as high as possible.

Also to be measured in related tests conducted under this section are the base pressures at which the UBA pop-off valve lifts, the base pressure at which the diluent add valve (if any) actuates, and the maximum flow rates of all purge valves and by-pass valves.

2. Quantities to be Measured:

   a. Mouthpiece (or oral-nasal) pressure re selected reference pressure

   b. UBA and mask position on test manikin (measure in sufficient detail so that the UBA and mask could be removed and replaced in <u>exactly</u> the same position

   c. Pressure at which the UBA exhaust (pop-off) valve lifts

d. Pressure at which the diluent add valve actuates (closed circuit UBA only).

e. Maximum flow rate attainable through all by-pass and/or purge valves. (If these valves are located in the system so that the flow across them is always sonic regardless of the test depth, as is the case for most UBA, then the maximum by-pass/purge flow rates need be measured only at the surface. Otherwise, they must be measured at each test depth.)

3. Quantities to be controlled:

a. Amount of gas added to and withdrawn from the mouthpiece or oral-nasal

b. UBA and mask position on the manikin

c. Setting of exhaust or "pop-off" valve

d. Supply pressure to the UBA

e. Supply gas mixtures

f. Manikin orientation

g. UBA tested wet or dry

h. Temperature

i. Depth

4. Equipment

a. Specialized equipment required

1) Large graduated syringe, preferably about 2 liters

2) 3-way valves and plumbing as shown in Figure 1

3) Test manikin and wet testing box

4) Differential pressure transducer and transducer indicator, 1 psid

5) Flowmeters (2), approximate sizes, 1.0 and 8.4 scfm air at 70°F. and 14.7 psia with a minimum working pressure of 600 psig

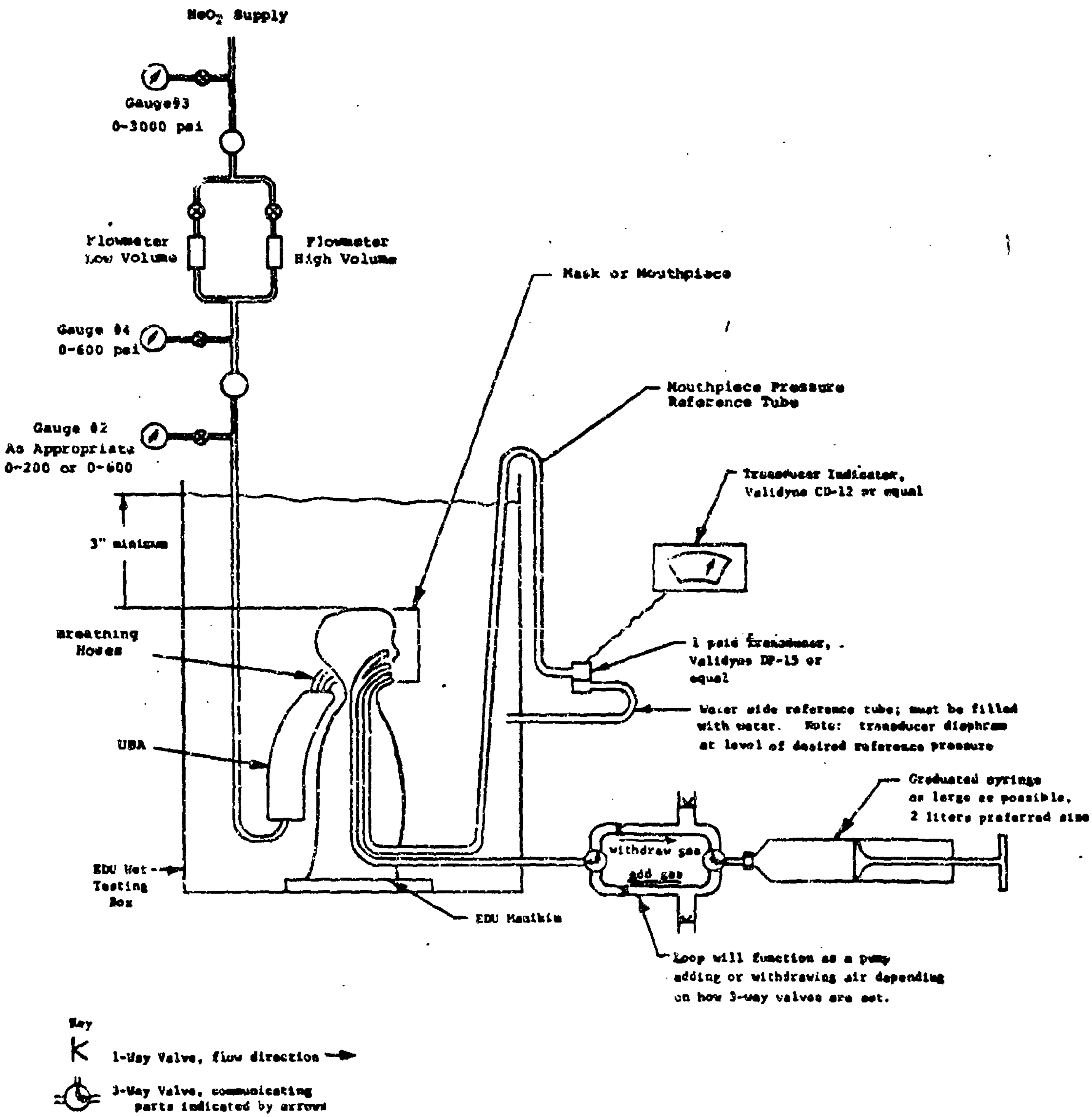


Figure 1

Test Equipment Set-Up, Underwater Breathing Apparatus Compliance Tests, Apparatus Wet.

For Dry Tests, Apparatus & Manikin need not be inside the Wet Testing Box

b. Set up the UBA test equipment generally as shown in Figure 1. Figure 1 is intended only as a guideline, and minor modifications can be expected to accommodate the particular apparatus being tested.

c. The UBA should be placed on the test manikin and jocked as nearly per manufacturer's instructions as possible. Measure the UBA position on the manikin in sufficient detail so that it can be exactly reproduced.

d. All manikin openings inside the UBA facemask except the openings to the syringe and pressure transducer must be closed, and if necessary, sealed. Leaks may invalidate the test. Leaks may be checked for by adding 20 cm H_2O pressure to the UBA and observing the rate of decay. A system with a pressure decay of less than 1 cm H_2O per 15 seconds at 20 cm H_2O pressure can be considered leak-tight for this case. For the compliance tests, the gas supplies to the UBA must be secured, and, if necessary, sealed. The exhaust valve should be closed as tightly as possible, and, if necessary, sealed shut.

e. The transducer line to the UBA and the syringe line must not be the same port.

f. The reference pressure for the transducer may be any convenient pressure, as long as the pressure used is recorded. Hydrostatic pressure at the level of the manikin's 7th cervical vertebra , at the level of the centerline of the manikin's mouth (as shown in Figure 1) or at any other appropriate level may be used. The Project Officer should determine ahead of time which reference pressure is to be used. See EDU Report 19-73 for more information on reference pressures.

5. Calibration

Calibrate the transducer and transducer indicator against a water or mercury manometer prior to each major test. Recheck calibration at the end of the test. The flowmeters are factory calibrated and should not need calibration unless there is evidence of damage.

6. Test Conditions and General Procedures

a. Compliance Tests

1) The UBA should be tested first dry, then wet. When tested dry, the UBA will have essentially the same compliance in all orientations. When tested wet, it will exhibit different compliance characteristics in different orientations with respect to the pull of gravity. Normally it will be sufficient to test the UBA only in the head-up vertical orientation shown in Figure 1 and the face-down, horizontal orientation. However, if ventilation tests (Section III,C.) are to be run with the UBA in other orientations, compliance tests should be performed with the UBA in those orientations, as well.

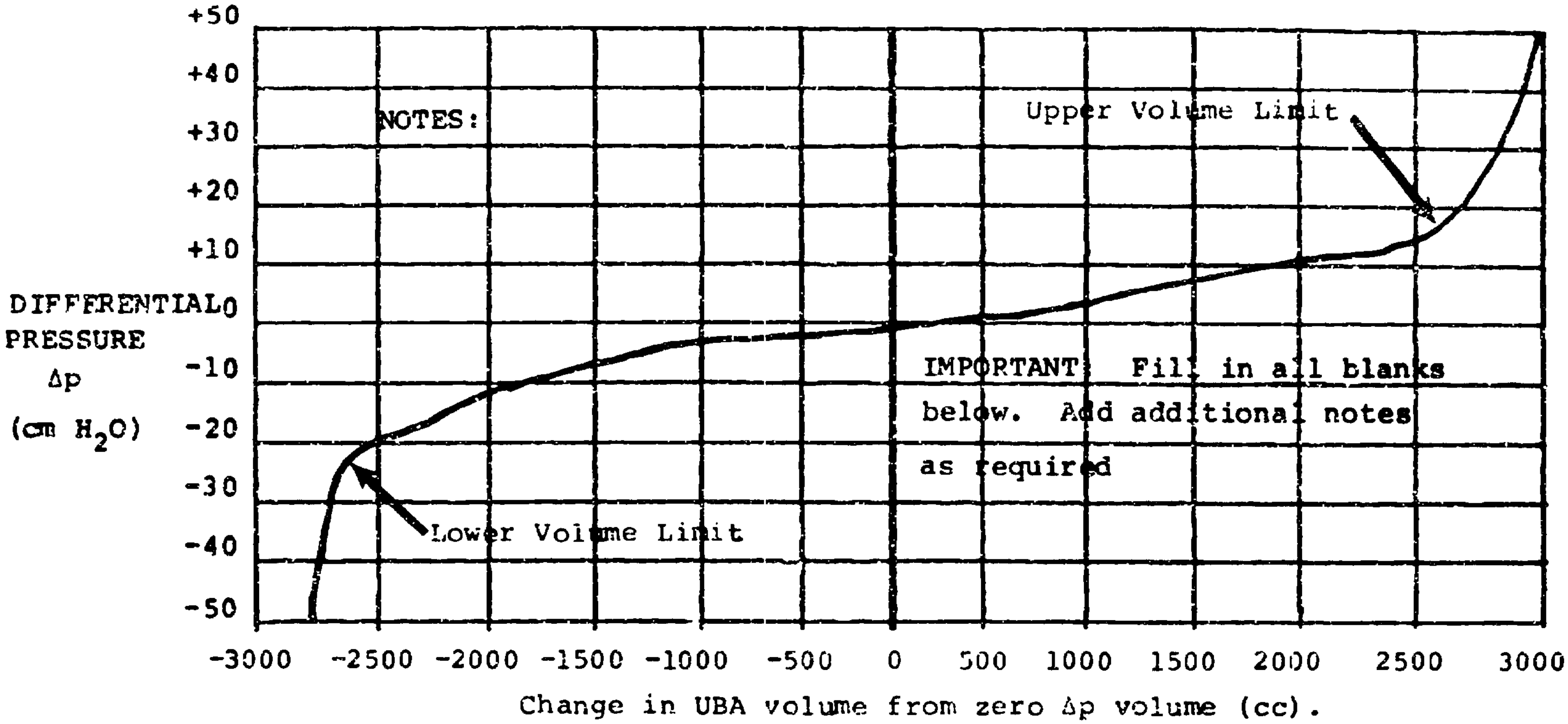
2) Normally this test will be performed only at 0 fsw and room temperature. However, the Project Engineer may order additional test conditions.

3) Secure all gas supplies to the UBA, seal if necessary. Set the exhaust (pop-off) valve for maximum back-pressure. If necessary, seal it closed to prevent unwanted leaks.

4) With the UBA dry and at zero Δp, add 100 cc air, record the UBA Δp indicated, and return to zero Δp. Now from the zero Δp volume again, add 200 cc air, record the UBA Δp indicated and return to zero Δp. Continue this process until the upper volume limit of the UBA system is reached. The upper volume limit is that volume above which small increases in volume require very large Δp increases. Now proceed to the lower volume limit in the exact same fashion: withdrawing 100 cc air from the zero Δp volume, recording the UBA Δp, returning to zero Δp, withdrawing 200 cc air, etc. Repeat two more times. If you did not get reproducible results, you have a major leak somewhere; fix it and try again.

5) Fill the test box with water to a level at least three inches over the top of the manikin and repeat 4) above.

6) Plot the results as shown in Figure 2.



Apparatus ____________ Date ____________ Recorder ____________

UBA and Manikin Orientation ______________________________

Reference Pressure ______________

UBA Dry ________ or Submerged ________

Depth __________ Temperature ______________

UBA Serial Number ______________

Mask Used, if any ____________________

Figure 2. Sample UBA Compliance Test Results

b. Exhaust (Pop-Off) Valve Tests

1) Remove the sealing agents installed in the exhaust valve in section III.B.6.a, if any.

2) Perform these tests with the UBA submerged. With the exhaust valve set at several representative settings, slowly add gas to the UBA with the syringe. For each setting, note the pressure at which bubbles first appear from the exhaust valve.

3) With the appropriate by-pass valve, admit a steady flow of 0.5 acfm to the UBA, record the pressure level reached. Repeat with a steady flow of 1.0 acfm. Do this for each of the exhaust valve settings used in 2) above.

4) Plot the results as shown in Figure 3.

c. Diluent Add Valve Tests (Closed Circuit UBA Only)

1) Perform these tests with the UBA submerged.

2) With the syringe slowly withdraw gas from the UBA until the diluent add valve is heard to open. Repeat several times with different diluent supply pressures. Note any effect of diluent supply pressure on the performance of the diluent add valve. For each test, record the diluent supply pressure and the pressure at which the diluent add valve opened.

d. By-Pass and/or Purge Valve Flow Rates

1) For these tests, remove the water from the test box and disconnect the breathing bags or diaphragm. There is a danger of rupturing the breathing bags or diaphragm when these tests are performed on the surface.

2) Semi-Closed Circuit UBA Only

a) Record the flow rate and pressure settings of the metering orifice.

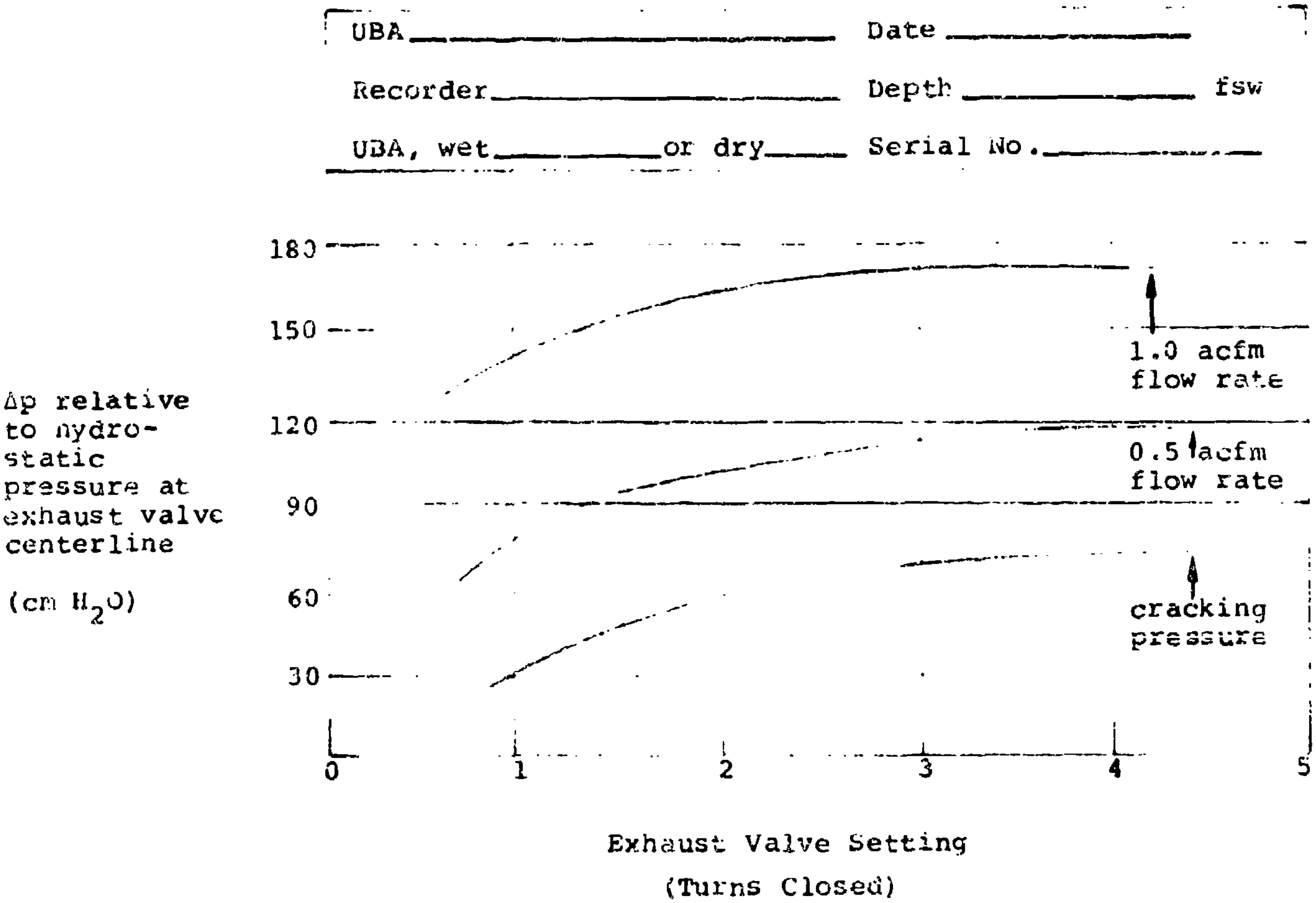


Figure 3. Sample Graph, UBA Maximum Pressure Versus Exhaust Valve Setting

b) Depress the by-pass valve fully. Record the flow rate achieved and the supply pressure to the UBA. If the by-pass valve draws directly from the umbilical or bottle gas supply (as most do), repeat this test on a variety of representative supply pressures.

c) Repeat this test on a variety of gas mixtures normally used with the UBA being tested.

3) Closed Circuit UBA Only

a) By hand, depress the diluent add valve fully, and record the flow rate and the diluent supply pressure. Repeat for a full range of representative diluent supply pressures.

b) Repeat a) above for the diluent by-pass valve.

c) Perform a) and b) above on all diluent gases normally used with the UBA under test.

d) Repeat a) above for the oxygen by-pass valve.

7. Data Handling

a. Compliance Tests

All results are to be recorded on a chart similar to Figure 2. Note that it is the Project Engineer's responsibility to correct for errors due to compression or expansion of the gas in the UBA and manikin plumbing. At 1 ata the error is 1 scc volume/cm H_2O pressure/liter of free volume.

b. Exhaust Valve Tests

Record the results on a chart similar to Figure 3.

c. All Other Tests

Record the data in neat tabular form unless otherwise directed by the Project Engineer.

d. For each test run calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and X-Y plotter.

e. The Project Engineer or his representative should keep a daily log of all significant events.

C. Ventilation Tests

1. Background

The pu. ose of these tests is to determine the ventilation characteristics of the UBA when it is in normal working order and normal working trim. The variables of primary interest are the breathing resistance, inspired PCO_2 levels, inspired PO_2 levels, and, in the case of semi-closed circuits UBA's, also the liter flow rate.

The breathing pressure data obtained from these tests should reflect the compliance results of Section III.B.

Measuring the duration of the CO_2 absorbant canister is not a goal of these tests. Canister duration tests should be run separately as noted in Section III. D. The tests outlined in this section are designed solely to determine the ventilation characteristics of the UBA given a properly operating CO_2 absorbant canister.

At this time, the mechanical breathing machine and related equipment do not have the ability to remove oxygen. Consequently, the ability of the UBA to maintain a safe PO_2 level cannot adequately be tested by this method. However, careful observations of liter flow rates in the case of semi-closed circuit UBA's, and observation of the PO_2 sensors in the case of closed circuit UBA's will give a good indication of how well the rig will perform when subjected to manned tests.

2. Quantities to be Measured

a. PCO_2 levels at the following locations:

1) Inhalation mixing box (inhaled PCO_2 level, CO_2 #1, Figure 4)

2) Exhalation mixing box (exhaled PCO_2 level, CO_2 #2, Figure 4)

3) Exhalation hose (CO_2 #3, Figure 4)

4) Inhalation hose (CO_2 #4, Figure 4)

5) Any other location(s) selected by the Project Engineer

b. Differential pressures between the following locations:

1) Mouthpiece pressure and hydrostatic pressure at the selected reference point

2) Mouthpiece pressure and the pressure at the canister inlet port (Figure 4, Δp Transducer #2)

3) Mouthpiece pressure and the pressure at the canister outlet port (Figure 4, Δp Transducer #3)

4) Any other locations as directed by the Project Engineer

c. Temperatures at the following locations:

1) Inhalation mixing box

2) Exhalation mixing box

3) Mouthpiece or mask, if thermister installed

4) Water bath

d. Relative humidity of the inspired gas and expired gas.

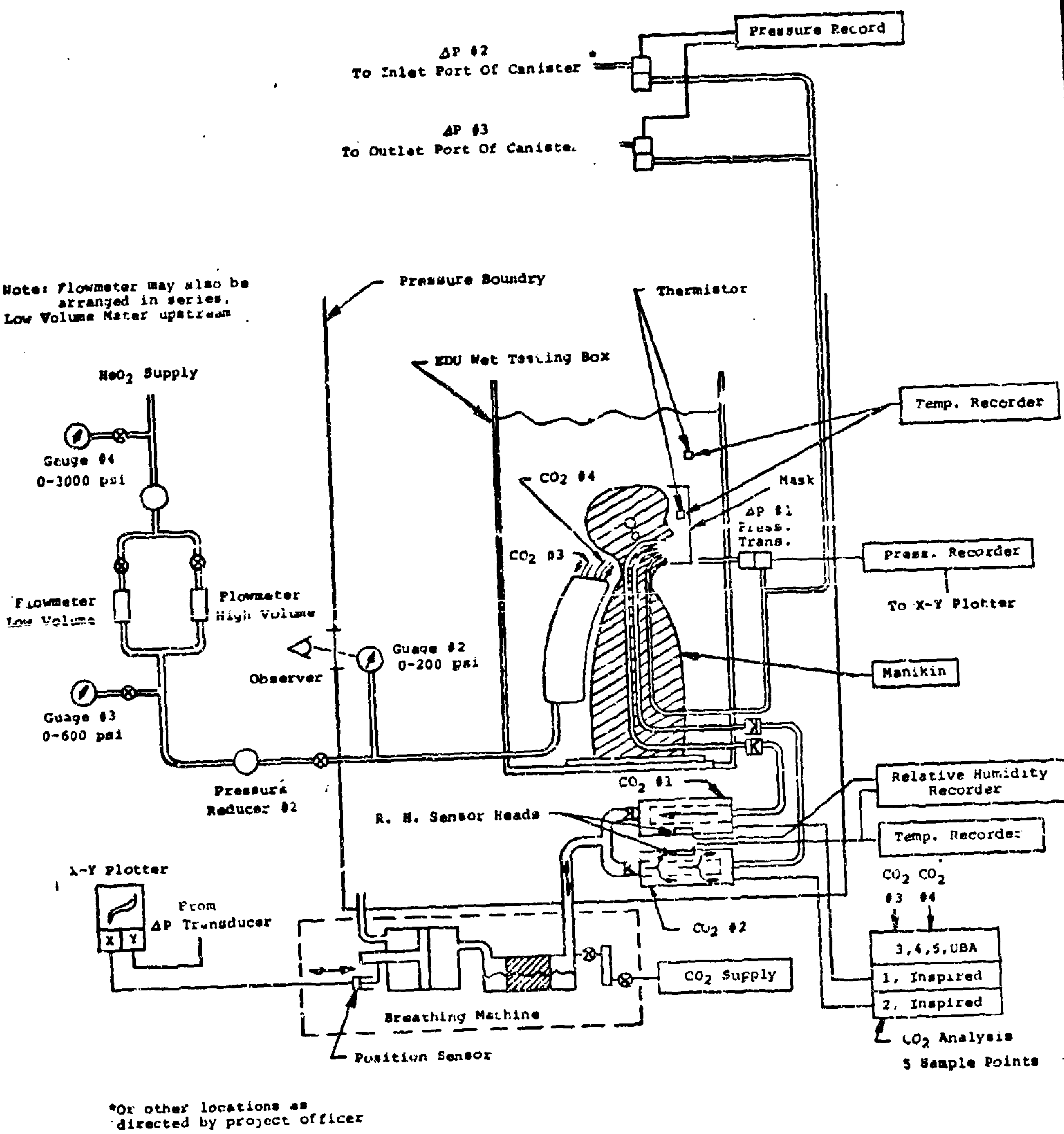


Figure 4
Test Equipment Setup, Ventilation Test Semi-Closed Circuit UBA's

3. Quantities to be Controlled

   a. Depth

   b. Supply over bottom pressure (Gauge #2, Figure 4)

   c. Exhaust (pop-off) valve setting

   d. Position of UBA on test manikin

   e. Manikin orientation

   f. UBA condition: wet

   g. Water bath temperature

   h. Gas media

   i. Umbilical size and length

   j. Manikin respiratory parameters

      1) CO_2 addition rate

      2) Breathing rate

      3) Tidal volume

      4) Volume-time waveform

      5) Exhaled gas temperature and relative humidity

4. Equipment set-up

   a. Specialized equipment required

      1) EDU manikin with double tracheas, one for inhalation, one for exhalation. Manikin should also have provisions for monitoring the pressure and temperature inside the mouthpiece.

      2) Porthole blanks with reach rods or flexible shafts tailored to the UBA to be tested; one for the exhaust valve, and one for the by-pass valve (semi-closed circuit UBA) or the diluent add by-pass (closed circuit UBA).

      3) Flowmeters (2) for gas supply line, approximate sizes, 1 and 8 scfm air at 70°F. and 14.7 psia with a 600 psig minimum working pressure (semi-closed circuit UBA's only).

4) Differential pressure transducers (3), approximate range ±5 psid, and associated signal conditions and recorders.

5) Thermistors and read-out unit.

6) Breathing machine with inhalation and exhalation mixing chambers.

7) At least two CO_2 analyzers, one with a range of 0 to 0.5% by volume, or 0 to 1% by volume; one with a range of 0 to 6% by volume. CO_2 levels #2 and #3 can be expected to run between 4 to 6% S.E., CO_2 levels #1 and #4 can be expected to run between 0 to 1% S.E.

b. Set up the equipment generally as shown in Figure 4. Figure 4 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test. Figure 4 shows an umbilical supplied semi-closed circuit UBA. The set-up for a closed circuit UBA would be identical except for the gas supply plumbing. Flowmeters are not required for closed circuit UBA's.

Self-contained UBA's, for this test, should be supplied from banks rather than from their own bottles. This test is rather lengthy, with frequent, and sometimes large, depth changes. Consequently, the gas supplies carried in most self-contained UBA's will be quickly exhausted, resulting in many delays to refill bottles.

c. Determine how much umbilical is appropriate to the depths to be tested and install it as shown in Figure 4.

d. One Δp transducer should be set-up to monitor the pressure differential between the mouthpiece interior and the hydrostatic pressure at the level of the 7th cervical vertibra (chamber ambient pressure if UBA is tested dry). Use a different reference pressure if so directed by EDU report 19-73. The other Δp transducers are to be set-up as directed by the Project Engineer.

e. The internal free volume of all inhalation plumbing components must not be greater than 10 liters. The internal free volume of all exhalation plumbing components must likewise be less than 10 liters. The internal free volume of components used for both inhalation and exhalation is to be charged against both 10 liter limits. 10 liters free volume is the most free volume that can be tolerated without introducing excessive errors due to pneumatic compliance (gas compressability). See EDU Report 20-73, Section III for more details.

f. Total mechanical compliance (hose stretch, etc.) of the breathing loop plumbing must be kept below .05 liter per 20 cm H_2O pressure change.

g. Water depth over the top of the manikin should be at least six inches. Water temperature should be 70 to 80° F.

h. Set up the X-Y plotter so that it makes plots of mouthpiece pressure versus inspired-expired volume. Plots of mouthpiece pressure versus inspiratory-expiratory flow rates may also be useful.

i. Great attention must be paid to the gas sampling system and the manner in which it is operated. The CO_2 sampling lines should be sized so that the time required for a gas sample to travel from the UBA to its appropriate analyzer is less than 30 seconds at the maximum test depth. However, the rate at which the gas is withdrawn from the UBA must be carefully monitored. It is very easy to withdraw so much gas for sampling purposes that the test becomes compromised. In general, breathing pressure measurements should not be made without first securing all of the gas sample lines.

j. All sampling lines should have small water traps, located downstream of the pressure reduction point.

k. All breathing loop components should have an I.D. of not less than 3/4". The lengths of the hoses carrying uni-directional flow are not critical and may be as long as required so long as the 10 liter free volume limit in e. above is observed. The lengths of the hoses and pipes carrying bi-directional flow are important and should be kept as short as possible with reasonable effort.

l. The output of the Δp transducers must be continuously recorded. Continuous recording of the outputs of the CO_2 analyzers is highly recommended. The output of the Δp transducer varies so rapidly with time that it cannot be read from a panel meter. The outputs of the CO_2 analyzers will vary enough with time to make accurate readings from a panel meter extremely difficult.

m. Test all equipment for free operation. Test for leaks. Repair and/or adjust as required. Leaks in the gas supply system (semi-closed UBA's only) can invalidate the flow rate data. Leaks in the breathing loop plumbing can invalidate the CO_2 data. The breathing loop plumbing can be considered leak tight if, with the manikin's mouth sealed or corked shut, the system will hold both a 20 cm H_2O pressure and a 20 cm H_2O vacuum with a pressure (vacuum) decay rate of less than 1 cm H_2O per 10 seconds at 20 cm H_2O pressure (vacuum).

5. Calibration

a. Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.

b. The transducers should be calibrated against a water or mercury manometer; the thermisters against 32°F. water and room temperature.

c. The flowmeter and gauges normally do not need daily calibration.

d. The CO_2 analyzers should be calibrated against at least 3 known gases each; full scale, zero and mid-range CO_2 concentrations. If the CO_2 analyzer calibrations are non-linear, several more calibration points and a graphical calibration record will be required.

e. Calibrate the X-Y plotter axes prior to each test. Re-check at the conclusion of each test. The Y-axis should read mouthpiece pressure; the X-axis, inspired-expired volume.

6. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical conditions for the complete test of a closed-circuit mixed gas UBA rated for a maximum service depth of 1000 fsw follow:

a.	Umbilicals	As required to connect UBA to test chamber O_2 and H_e headers.
b.	Supply Pressures	3000, 2000, 1000 psig and 300 psiob
c.	Test Depths	50 fsw increments to 1000 fsw
d.	Exhaust (pop-off) valve setting	Fully closed, 1/2 open, fully open or as recommended by manufacturer
e.	Position of UBA on Manikin	Normally jocked position. Be sure this position is known in sufficient detail so that it can be reproduced exactly.
f.	Manikin Orientation	Face-down horizontal and head-up vertical. Other orientations may also warrant testing.
g.	UBA condition	Wet
h.	Water Bath Temperature	70° to 80° F.
i.	Manikin Respiratory Parameters*	
	CO_2 Add. Rate	.04 X RMV slpm (ex. 1.6 slpm at 40 lpm RMV)
	Breathing Rate	15, 20, and 25 breaths per minute

* Parameters recommended by EDU Report 19-73

Tidal Volume	1.5, 2.0, and 2.5 liters per breath respectively at breathing rates of 15, 20, and 25 bpm
Volume-Time Waveform	Flattened Sinusoid with an exhalation to inhalation time ratio of 1.1 - 1.0 and a ratio of peak flow to minute volume of 2.7
Exhaled Gas Temperature	97° ± 2° F.
Exhaled Relative Humidity	Saturated at 97° F.

The test conditions for a semi-closed circuit UBA rated for 1000 fsw would be similar. The principal differences would be the addition of a test condition specifying the umbilical to be used, and the gas mixtures, supply pressures, and liter flows to be used.

7. General Procedures

a. These tests are normally done only with the UBA wet.

b. Test all of the conditions of interest on the surface. Get a feel for effects of pop-off (exhaust) valve settings and for the effects of various breathing bag/diaphragm inflation levels.

c. Test the UBA under pressure. Test under the test conditions designated by the Project Engineer. The best sequence to follow is usually to do all of the test conditions at 0 fsw, then 50 fsw, etc. on down to maximum test depth.

d. During descent be very careful not to travel too fast and produce excessively negative pressures in the UBA relative to chamber pressure. This can quickly result in a flooded rig.

e. It is usually best to let the breathing machine run continuously unless d. above requires that it be secured during descent.

f. During all times when the respiratory load on the UBA is being increased (increasing minute volume or increasing depth) watch the mouthpiece Δp transducer output very carefully. If excessively negative Δp's are observed, stop or slow down.

g. During ascent from the maximum test depth repeat 25 to 50% of the test readings taken during descent. This checks for reproducibility of the data.

h. Maintain each test condition until all values stabilize. This may take as long as 15 minutes.

i. If canister break-through occurs (CO_2 level #4, canister return, exceeds 0.5% S.E.), return to the surface obeying g. above, replace the CO_2 absorbant, return to the depth of break-through and complete the tests desired.

j. Repeat c. and g. above as many times as required to obtain good confidence in the data.

k. Take care that the amount of gas being drawn out the gas sample lines does not disturb conditions in the UBA. It is usually wise to make the mouthpiece Δp measurements and X-Y plots with all the sample lines secured.

l. To the extent possible, all emergency breathing modes should also be tested. This, however, will most probably require a separate test run with somewhat different instrumentation. If the emergency breathing mask is open-circuit, demand breathing from an umbilical supply, the emergency breathing mode is equivalent to Bandmask diving. See EDU Reports 2-73 and X-74 for procedures and instrumentation set-ups for testing a Bandmask type system.

8. Data Handling

a. On-line cross checking of data values is essential for this test. The best cross check to use is simple CO_2 conservation. There are two checks that can be used, as follows:

1) PCO_2 #2 - PCO_2 #1 should equal 4.0% S.E. ± .3% S.E.

2) The CO_2 addition rate should equal the CO_2 disappearance rate.

$$CO_2 \text{ in} = CO_2 \text{ out} = (PCO_2\#3 - PCO_2\#4) \times (RMV) + (PCO_2\#3) \times (\text{gas consumption rate})$$

The first term on the right hand side of the equation is the rate of CO_2 removal by the CO_2 absorbant canister; the second is the rate at which CO_2 is exhausted out the exhaust valve. The CO_2 disappearance rate calculated as above should equal the CO_2 add rate ± 10%.

b. Record at each test condition all measured and controlled quantities on a pre-made data sheet. Carefully annotate all strip recordings or other permanent data records so that the data can be identified.

c. For each test run, calibration records for each instrument calibrated must be made, clearly annotated, and attached to the data generated by each respective instrument during the runs to which the calibration record applies. This applies in particular to instruments that generate written records such as the strip chart recorders and the X-Y plotter.

d. Plot the recorded data as directed by the Project Engineer.

e. From the plots of mouthpiece pressure versus inspired-expired volume made on the X-Y plotter, calculate the external work of breathing expended by the manikin. Compare against the .17 Kg-m/liter ventilation limit proposed by EDU Report 19-73. If the work of breathing standards proposed by this report are adopted, a plot of the external work of breathing will also be required.

f. The Project Engineer or his representative should keep a daily log of all significant events.

D. $\underline{CO_2 \text{ Absorbent Canister Duration Tests}}$

1. Background

The purpose of these tests is to determine the expected lifetime of the CO_2 absorbent canister under all of the conditions in which the UBA will be expected to operate.

These tests are very similar to those of Section III. C. The experimental set-up is almost identical. The principal differences are in the test conditions selected. In these tests the ventilation conditions in the UBA are held constant (manikin RMV, liter flow, exhaust valve setting, etc.) and the temperature of the water bath is varied. In Section III. C. the reverse was true.

Canister lifetime tests are extremely time consuming. Round-the-clock operation should be considered.

2. Quantities to be Measured

The quantities to be measured are the same as those in Section III. C. 2. except:

a. The temperature of the gas entering and leaving the CO_2 absorbent canister must also be measured.

b. Only the mouthpiece Δp transducer (Δp Transducer #1, Figure 4) is necessary. The others may be eliminated.

c. The expired gas temperature and humidity are of critical importance in this test whereas in Section III. C. 2. they were of secondary interest.

3. Quantities to be Controlled

The quantities to be controlled are the same as those in Section III. C. 3. Water bath temperatures, manikin exhaled gas temperature and relative humidity are, however, of critical importance here whereas in Section III. C. 3. they were of secondary interest.

4. Equipment Set-Up

a. The recommended equipment set-up is identical to that outlined in Section III. C. 4. except:

1) Thermistors must be added to monitor the temperature of the gas entering and leaving the CO_2 absorbent canister.

2) Δp transducers #2 and #3 may be removed.

b. Precise ($\pm 2^{\circ}F$) control of the water bath temperature is essential.

5. Calibration

The calibration procedures are the same as those outlined in Section III. C. 5.

6. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test. Typical test conditions for a complete canister lifetime test follow:

a.	Umbilicals	As required to connect the UBA to the chamber O_2, He or Mixed Gas headers as appropriate
b.	Supply Pressures	1000 psig or as recommended by the manufacturer
c.	Test Depths	3 depths representative of the depth range in

		which the apparatus is to be used
d.	Supply Gas Mixture	Use mixtures representative to the depths chosen in c. above
e.	Exhaust Valve Setting	As recommended by the manufacturer
f.	Position of UBA and mask on manikin	Normally jocked position. Be sure this position is known in sufficient detail that it can be exactly reproduced.
g.	Manikin Orientation	Head-up vertical
h.	UBA Condition	Wet
i.	Water Bath Temperatures	70°F, 60°F, 50°F, 40°F, 32°F, additional temperatures as directed by Project Engineer
j.	Manikin Respiratory Parameters*	
	CO_2 Addition Rate	2.5 slpm
	Breathing Rate	25 breaths per minute
	Tidal Volume	2.5 liters
	Volume-Time Waveform	Flattened Sinusoid with an exhalation to inhalation time ratio of 1.1/1.0 and a ratio of peak flow to minute volume of 2.7
	Exhaled Gas Temperature	97 ± 2°F
	Exhaled Relative Humidity	Saturated at 97°F

7. General Procedures

a. The only test conditions which are not constant throughout are depth and water bath temperature.

*Severe Work Rate Parameters Recommended by EDU Report 19-73.

The best procedure is usually to test all of the desired water bath temperatures at 0 fsw, then go to 100 fsw, etc. on down to the maximum depth to be tested.

b. Each individual test will consist of running the canister until breakthrough at one depth and one water bath temperature. The test is considered to start when the breathing machine is turned on. Once turned on, the breathing machine and CO_2 add system should not be secured until the test is completed.

c. Run the test until the CO_2 level in the canister return line reaches 2.0% S.E.

d. During these tests, once started, the breathing machine must run continuously. During descent evolutions, use the by-pass valve to admit extra gas if required to maintain a satisfactory mouthpiece Δp. Watch the mouthpiece Δp very carefully during descent.

e. Due to the length of time required for each test, individual test runs are normally not repeated as long as everything worked properly and the test results are consistent with the results from the other canister lifetime test runs.

f. Take care that the amount of gas being drawn out the gas sampling lines does not excessively disturb conditions in the UBA.

8. Data Handling

a. The data handling procedures are essentially the same as those of Section III. C. 8.

b. The CO_2 cross checking procedures are identical with those of Section III. C. 8. a. As before, they should be done on-line.

c. The principal purpose of these tests is to determine the expected canister lifetime as a function of depth and water temperature. Consequently only the CO_2 level versus time data need be plotted separately. Whether or not other data obtained (UBA gas consumption, mouthpiece Δp, etc.) is to be plotted is to be determined by the Project Engineer. The best way to handle this data will probably be to plot it as additional data points on the graphs and plots made as a result of the tests outlined in Sections III. B. and III. C.

E. Manned Dives, Subjective Evaluation

1. Background

Definitive manned testing of the UBA for ventilation adequacy will be accomplished under section III. F., Physiological Testing.

This section is concerned with essentially subjective tests to obtain a rough measure of the comfort, human engineering and mobility of the UBA. To determine those qualities accurately requires a rather large program of manned tests considered to be outside the scope of this evaluation. The tests outlined below can be accomplished quickly and relatively easily. They will provide an indication of the UBA mobility, human engineering (are the controls easy to operate, etc.) and comfort which should be sufficient to point out any really serious troubles that must be addressed before larger scale manned tests such as Techeval/Opeval are undertaken.

The instrumentation recommended in this section is relatively sparse. This is so not because of design, but rather due to the difficulty in making measurements on a diver who is free to move about as he chooses in a relatively large body of water.

2. Pool Tests

a. The tests will be conducted at the NDW Swimming Pool, although any suitable pool may be used.

b. The purpose of these tests is to achieve a reasonable estimation of the apparatus comfort, human engineering, and mobility when swimming in essentially open water.

WARNING!

DURING ALL POOL SWIMS THERE MUST BE ONE SAFETY DIVER OUTFITTED IN EITHER SNORKEL OR SCUBA GEAR WITH EACH TEST DIVER.

c. The UBA pre-dive and post-dive check-outs are to be performed as required for the UBA under test.

d. Static tests

1) Lying face down on the bottom, observe the hydrostatic breathing resistance, buoyancy, and torque characteristics.

2) Lying face up on the bottom, make the same observations.

3) Standing completely submerged, make the same observations.

4) Try to attain neutral buoyancy at mid-depth without swimming in each of the following positions: (a) vertical, head down, (b) vertical, head up, (c) horizontal, face down, and (d) horizontal, face up.

5) As each subject completes the sequence, record his comments and recommendations immediately.

e. Swimming tests

1) Have each of four subjects swim 8 laps of the pool at an average speed of 0.8 knots (2½ minutes per lap at NDW Pool.

2) Instruct the subject to observe the following factors during the test:

aa. general comfort of the apparatus

bb. general fit of the harness

cc. general swimmability

dd. specific buoyancy characteristics

ee. specific torque characteristics

3) As each subject completes his swim, record his comments and recommendations immediately. Use the Diver Equipment Analysis questionaire contained in Appendix A or its equivalent.

f. Instrumentation for pool tests

The pool test swims will normally be conducted with un-instrumented apparatus. However, where applicable, bottle pressures pre- and post-swim, liter flows, etc. should be recorded. All apparatus malfunctions must be recorded.

3. Chamber Swims

a. Purpose

The purposes of these tests are to:

1) Obtain a reasonable estimation of the comfort, human engineering and mobility of the UBA when it is used at its normal operating depths.

2) Obtain some confirmation of the breathing machine test data gathered under Section III. C.

b. Quantities to be Measured

1) UBA gas comsumption rate

aa. In semi-closed circuit UBA, measure liter flow

bb. In closed circuit UBA, measure bottle pressure drops

2) Inspired PCO_2 level

3) Inspired PO_2 level

4) Mouthpiece Δp relative to hydrostatic pressure at the 7th cervical vertebrate. If a different reference pressure was used in Section III. C., then use that reference pressure instead.

5) Inspired gas temperature (if appropriate)

6) UBA exhaust valve positions selected by the divers (if valve adjustable)

c. Quantities to be Controlled

1) Depth

2) Diver work tasks

3) Wetpot temperature

4) Supply overbottom pressure (umbilical supplies UBA only)

5) Gas media

d. Equipment Set-Up

1) Specialized equipment required

aa. Flowmeters, approximate sizes, 1 and 8 scfm air at 70°F and 14.7 psia with a 600 psig minimum working pressure (required for umbilical supplied semi-closed circuit UBA only)

bb. Differential pressure transducers, approximate range ±5 psid, and associated signal conditions and recorders

cc. Thermistors and read-out unit

dd. CO_2 analyser, 0 to 1.0% by volume range with recorders

ee. Oxygen analyser, 0 to 25% by volume range, with recorders

2) Set up the test equipment generally as shown in Figure 5. Figure 5 is intended only as a guide, and minor equipment modifications can be expected to accommodate the particular apparatus under test.

3) Regular umbilicals are not necessary for these tests. Any suitable leader hoses will do.

4) All gas sampling lines should have water traps, downstream of the pressure reducing valves.

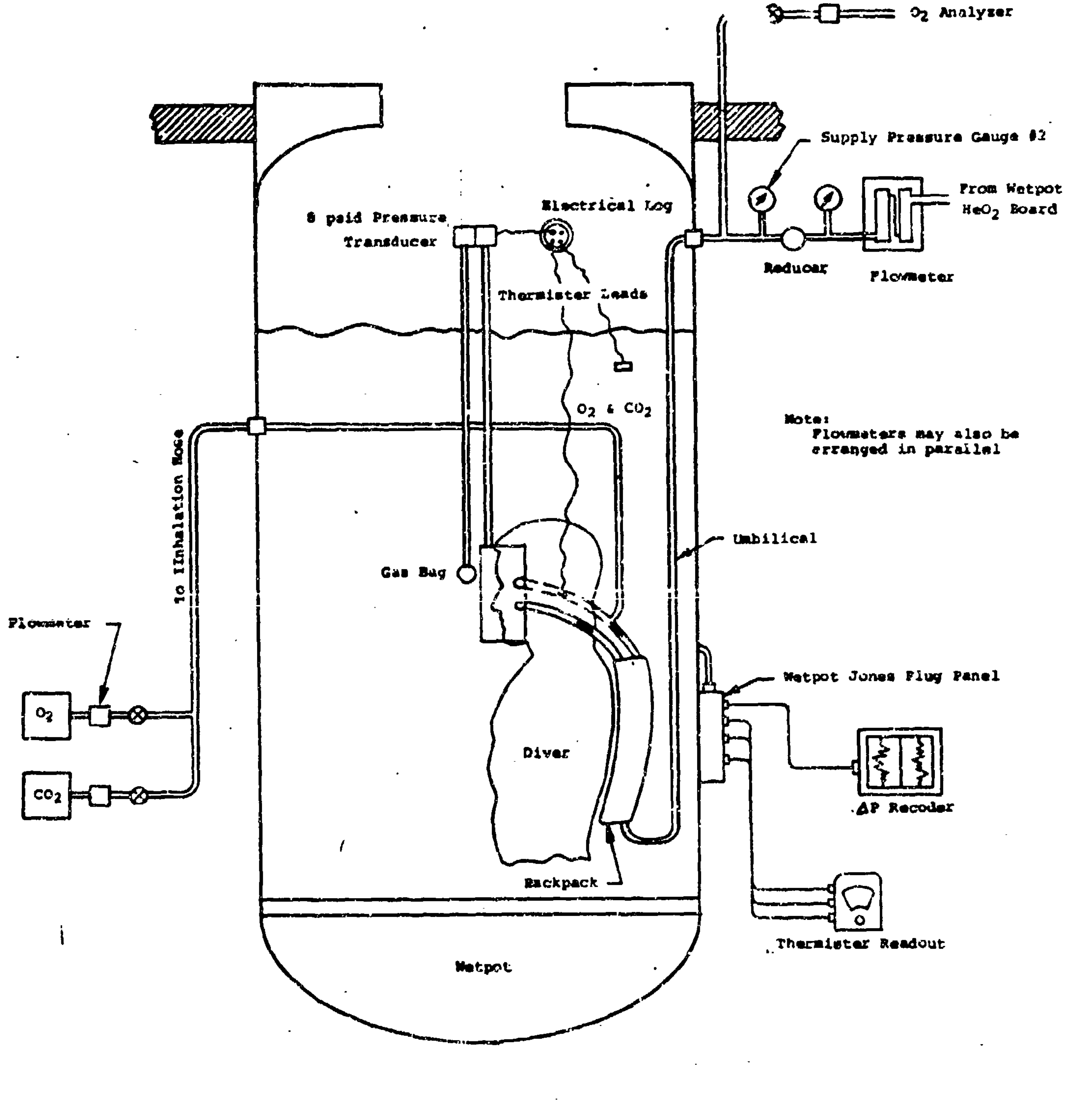


Figure 5
Test Equipment Set-up,
Manned Subjective Test,
Semi-Closed Circuit Mixed
Gas UBA

5) The outputs of the O_2 and CO_2 analysers should be continuously recorded. The output of the Δp transducer must be continuously recorded. Hand recordings of the Δp, O_2 and CO_2 values every 5 minutes, as is commonly done, are of little value due to often rapidly changing values.

6) The sample gas flow rates to the O_2 and CO_2 analysers must be kept as low as possible consistant with an acceptable lag time in the instrument response. Too high sample flow rates will affect the breathing performance of the UBA. In self-contained apparatus, too high flow rates will also quickly exhaust the gas supply. Too low sample flow rates or excessively long and/or large sample lines will cause the analyser response to be several minutes behind the actual O_2 and CO_2 levels in the UBA.

e. Calibration

1) Calibrate all adjustable instruments immediately prior to each major test. Re-check calibrations at the conclusion of the test.

2) The Δp transducers should be calibrated against a water or mercury manometer; the thermistors against $32^{\circ}F$ water and room temperature.

3) The flowmeter and gauges normally do not need daily calibration.

4) All gas analysis instruments should be calibrated against at least 3 known gases each: full scale, zero and mid-range concentrations. If the analysers, especially the CO_2 analysers, are non-linear, several more calibration points and a graphical calibration record is required.

f. Test Conditions

The test conditions to be covered will vary with the apparatus to be tested and with the degree of testing required. The Project Engineer should determine the conditions to be tested prior to commencing the test.

It is not possible to predict what test conditions should be used. The following guidelines however should be followed:

Depth	At least 5 depths representative of the depth range in which the UBA is to be used
Supply Pressure Supply Gas Liter Flow	As recommended by operations manual for UBA under test
Wetpot Temperature	70°F or above (due to wetpot steel NDT considerations)
Diver Work Tasks	See Section III. E. 4. g. 3)

g. General Procedures

1) For a reasonably thorough subjective evaluation at least 5 dives should be made to each depth. Always use divers who have had sufficient exposure in the UBA so that they feel familiar with its controls.

2) Normal U.S. Navy diving procedures are to be followed.

3) The normal work routine while the divers are on the bottom consists of 10 minute periods of "moderate" work separated by 5 minute rest periods. Normally two divers are used and they alternate work tasks between lifting a 70-pound weight (78 lbs dry) a distance of 2½ feet 10 times per minute and swimming against a trapeze designed to exert a steady backward force of 6.0 lbs. For an average diver, exerting a stationary swimming force of 6.0 lbs. produces an oxygen demand of approximately 1.26 standard liters per minute (4). This is equivalent to a respiratory minute volume of approximately 30 liters per minute (5) or to swimming in SCUBA at a steady

speed of approximately 0.8 knots (4)(5). An oxygen demand of 1.26 slpm results in a CO_2 production of about 1.13 slpm (6).

When possible, short periods of heavy and severe work should also be used. These can be effected by increasing the trapeze force to 10 and 12 lbs. respectively. Swimming against a 10 lb. stationary force is roughly equivalent to swimming at a speed of 1.0 knots. It can be expected to produce an oxygen consumption of 1.9 slpm, an RMV of 48 lpm, and a CO_2 production rate of 1.8 slpm (4)(5)(6). Swimming against a 12 lb. stationary force is roughly equivalent to swimming at a speed of 1.3 knots. This represents maximal effort and it can be expected to produce an oxygen consumption of about 3.0 slpm, an RMV of about 70 lpm and a CO_2 production rate of about 2.9 slpm (4)(5)(6). It can also be expected to very quickly produce very tired divers. In general the heavy and severe work loads should be held to not more than 5 minutes duration.

4) At the conclusion of each dive, the diver should fill out the applicable portions of the Diver Equipment Subjective Analysis Questionnaire reproduced in Appendix A or its equivalent.

h. Data Handling

1) Record at <u>each</u> test condition <u>all</u> measured <u>and controlled</u> quantities on a <u>pre-made</u> data sheet. Carefully annotate <u>all</u> strip chart recordings or other permanent data records so that the data can be identified.

2) Compare the CO_2 levels and mouthpiece differential pressures measured to the results of Section III. C.

3) Tabulate and/or plot the data obtained as directed by the Project Engineer. There is usually sufficient variability in the data from these dives to make concise plotting difficult.

4) The Project Engineer or his representative should keep a daily log of all significant events.

5) For each day's test dives, calibration records must be made, clearly annotated and attached to the data generated by each respective instrument during the runs to which the calibration record applies.

F. Manned Dives, Physiological Testing

1. Background

The purpose of these tests is to determine quantitatively the ability of the apparatus under test to support the physiologic and respiratory requirements of a diver at hard work. The tests are normally conducted by the EDU Medical Department.

The procedures and equipment used for these tests are still being refined. A detailed protocol covering these tests is expected to be published by the EDU Medical Department sometime in the second quarter of CY 1974.

IV. INSTRUMENT SPECIFICATIONS

Instrument	Type Normally Used	Accuracy	Minimum Frequency Response
Flowmeters	Variable Area	±2% of full scale	0.5 Hz
ΔP Transducers	Variable Reluctance	±1/2% of full scale	200 Hz
Transducer Indicators	Meters	±1% of full scale	1 Hz
Oxygen Analyzers	Paramagnetic	±0.5% by volume	0.1 Hz
CO_2 Analyzers	Non-dispersive Infrared	±1% of full scale	1 Hz
Thermistors	Thermocouple	±1° F	0.1 Hz
Relative Humidity Instruments	--	±3%	0.1 Hz
Pressure Gauges	Bourdon Tube	±1/4% of full scale	0.5 Hz
Strip Chart Recorders	Electric, Oscillographic	±1% of full scale 50 mm chart width	40 Hz at full chart width
X-Y Plotter	--	±1% of full scale	maximum slewing speed = 40 in/sec maximum acceleration 1400 in/sec^2 in X direction, 2000 in/sec^2 in Y direction

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APPENDIX A

DIVER EQUIPMENT
SUBJECTIVE ANALYSIS

DIVER EQUIPMENT
SUBJECTIVE ANALYSIS

DIVERS NAME ______________________________ DATE ________

LOCATION ____________________ DEPTH ________ TIME ________

EQUIPMENT SET-UP

MANUFACTURER ______________________________ MODEL ______

TYPE RIG ________________ GAS USED ____ $\%O_2$ ____ $\%N_2$ ____ % He

SUPPLY-PRESSURE BEFORE ____________ AFTER ______________

REGULATOR PRESSURE BEFORE ____________ AFTER ______________

ORIFICE SIZE ___________ LITER FLOW BEFORE ____ AFTER ____

HELMETS AND MASK

1. WHAT INLET AND EXHAUST SETTINGS DID YOU FIND COMFORTABLE WHILE WORKING AND WHILE STANDING AT REST? EXPRESS VALVE SETTINGS AS THE NUMBER OF TURNS OPEN OR CLOSED.

   (example: inlet 2 1/4 turns open).

	INLET	EXHAUST
WORK	_____	_______
REST	_____	_______

TYPE OF WORK ____

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2. RATE AND COMMENT ON THE INHALATION RESISTANCE OF THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

3. RATE AND COMMENT ON THE EXHALATION RESISTANCE OF THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

4. RATE AND COMMENT ON THE EASE OF DONNING THE HELMET/MASK AND ITS ACCESSORIES.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

5. RATE AND COMMENT ON THE HELMET/MASK WEIGHT OUT OF THE WATER.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

6. RATE AND COMMENT ON THE HELMET/MASK BUOYANCY IN THE WATER.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

7. RATE AND COMMENT ON THE FIT AND COMFORT OF THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

8. RATE AND COMMENT ON THE NOISE LEVEL IN THE HELMET.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

9. RATE AND COMMENT ON THE ADEQUACY OF THE COMMUNICATIONS IN THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

10. RATE AND COMMENT ON THE ACCESSIBILITY AND OPERATION OF CONTROL VALVES.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

11. RATE AND COMMENT ON THE VISIBILITY FROM THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

12. RATE AND COMMENT ON THE EASE OF CLEARING WATER FROM THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

13. RATE AND COMMENT ON THE HELMET/MASK TORQUE.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

14. WHAT IS YOUR OVER ALL EVALUATION OF THE HELMET/MASK.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

BREATHING APPARATUS

15. RATE AND COMMENT ON THE WEIGHT OF THE APPARATUS OUT OF THE WATER.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

16. RATE AND COMMENT ON THE BUOYANCY OF THE APPARATUS IN THE WATER.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

17. RATE AND COMMENT ON THE ACCESSIBILITY AND OPERATION OF CONTROL VALVES.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

18. RATE AND COMMENT ON THE SWIMMABILITY OF THE APPARATUS.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

19. RATE AND COMMENT ON THE APPARATUS TORQUE.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

20. RATE AND COMMENT ON THE INHALATION BREATHING RESISTANCE.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

21. RATE AND COMMENT ON THE EXHALATION BREATHING RESISTANCE.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed

22. WHAT IS YOUR OVERALL EVALUATION OF THE APPARATUS.

dangerous to life	acceptable for fleet use	excellent feature impossible to improve on	not observed